M.O. 613 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 85, No. 1,014, DECEMBER 1956

SNOW SURVEY OF GREAT BRITAIN

Season 1955–56

The basic material for this report has been obtained, as in previous years, from returns made by voluntary observers who have provided, month by month, daily records of snowfall and of any snow cover in sight. These records, from a network of stations distributed over the country, are augmented by data extracted from the regular monthly returns from official weather stations and from voluntary climatological stations reporting to the Meteorological Office. Without the co-operation of all those responsible for these voluntary observations, this report could not have been prepared in anything like its present detail.

The measurements of snow depth are given in inches and refer in general to 0900 G.M.T. or thereabouts.

Summary of 1955–56 season.—Snowfall was about average, taking the season as a whole, and occurred mainly during January and February. There was little snow in November or after March except in Scotland. During January snow was most frequent in Scotland, but in February it was almost as frequent in the Midlands and eastern England as further north. Figs. 1 and 2 show the number of days of snow falling and snow lying respectively during the season and are based on observations from some 450 stations. Snow fell on more than 70 days in the Grampians, 50 over the high ground in the Southern Uplands, 40 in the Pennines and 30 over most of the country north of a line roughly from Aberystwyth, Cardiganshire, to Felixstowe, Suffolk, except western coastal districts, areas around the Humber basin and a broad belt across the country from the Firth of Clyde to the Firth of Forth. Few places had less than 10 days of snow and these were mainly along the south-west coast. The number of days with snow lying (at 0900 G.M.T.) during the season exceeded 60 in the Grampians, 50 in the Cheviots and northern Pennines, and 40 around Buxton, Derbyshire, the Yorkshire Wolds, the North Yorkshire Moors and in parts of Ross and Cromarty, Scotland. Snow lay for less than 10 days in most south and west coastal areas. For most of the country snow was deepest around February 21 (Fig. 3). Undrifted snow had on that day accumulated to a level depth of more than 10 in. in Kent, 8 in. in parts of East Anglia, Lincolnshire and Durham, and more than 12 in. in parts of the East Riding of Yorkshire and around the Cairngorms.

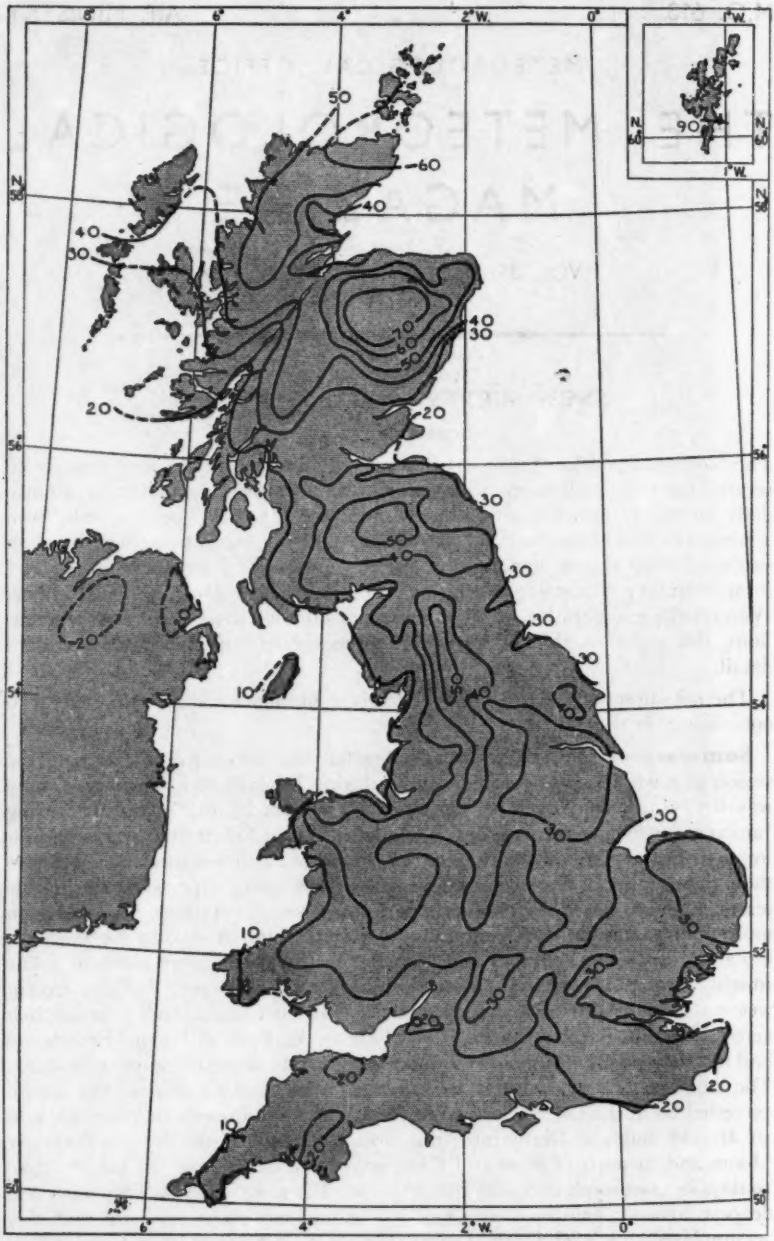


FIG. 1—NUMBER OF DAYS OF SNOW FALLING SEPTEMBER 1955 TO MAY 1956

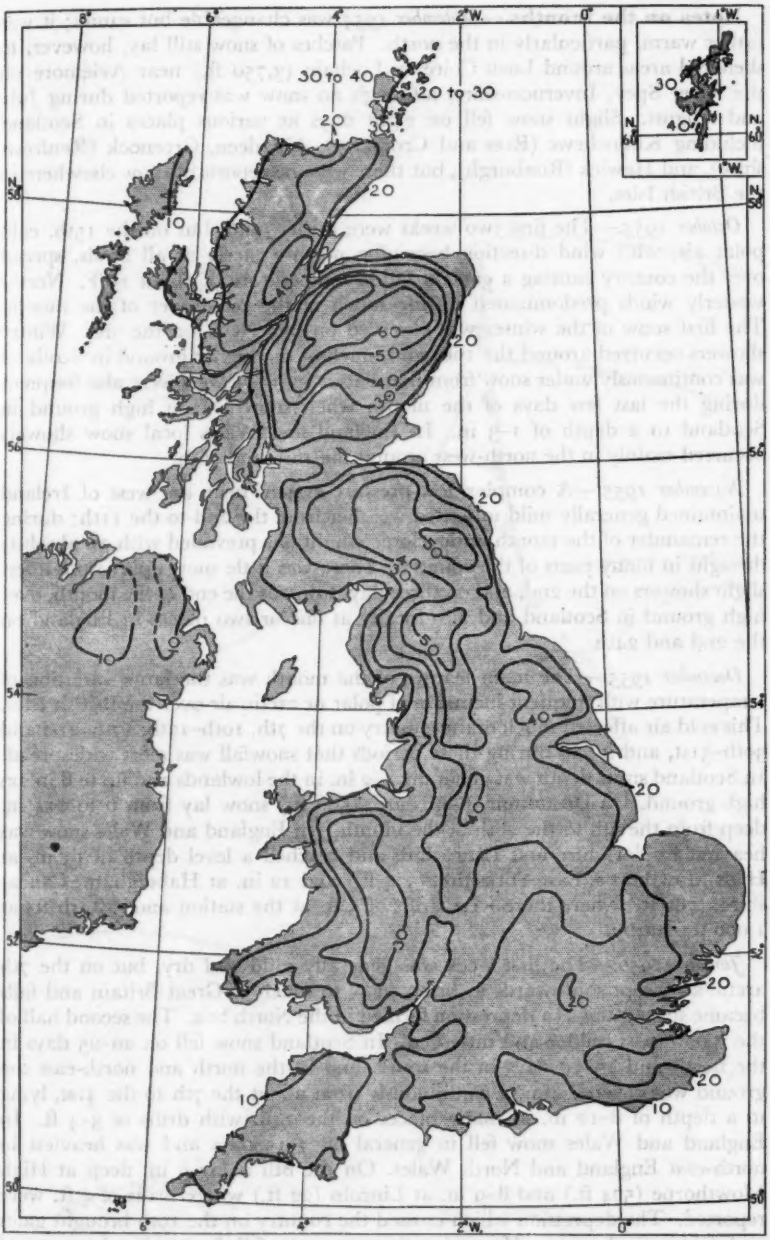


FIG. 2—NUMBER OF DAYS WITH SNOW LYING SEPTEMBER 1955 TO MAY 1956

Notes on the months.—*September 1955* was changeable but sunny; it was rather warm, particularly in the north. Patches of snow still lay, however, in sheltered areas around Loch Coire an Lochain (3,750 ft.) near Aviemore on the River Spey, Inverness-shire, although no snow was reported during July and August. Slight snow fell on eight days at various places in Scotland including Kinlochewe (Ross and Cromarty), Aberdeen, Greenock (Renfrewshire), and Hawick (Roxburgh), but there were no reports of snow elsewhere in the British Isles.

October 1955.—The first two weeks were rather mild, but on the 15th, cold polar air, with wind direction becoming north-westerly at all levels, spread over the country causing a general fall of temperature of about 15°F. North-westerly winds predominated during much of the remainder of the month. The first snow of the winter was observed on Ben Nevis on the 3rd. Wintry showers occurred around the 16th and much of the higher ground in Scotland was continuously under snow from that date. Snow showers were also frequent during the last few days of the month when snow lay on high ground in Scotland to a depth of 1–3 in. In England and Wales local snow showers occurred mainly in the north-west around the 16th and 26th.

November 1955.—A complex low-pressure system near the west of Ireland maintained generally mild unsettled weather from the 2nd to the 11th; during the remainder of the month anticyclonic conditions prevailed with an absolute drought in many parts of the country. There was little snow apart from a few slight showers on the 2nd, and on three days towards the end of the month, over high ground in Scotland and also locally at one or two places in England on the 2nd and 24th.

December 1955.—The main feature of the month was the large variation of temperature with frequent incursion of polar or arctic air over the British Isles. This cold air affected much of the country on the 7th, 10th–12th, 17th–21st and 30th–31st, and it was during these periods that snowfall was most widespread. In Scotland snow depth was generally 1–2 in. in the lowlands and up to 6 in. on high ground. At Drummuir, Banffshire, (500 ft.) snow lay from 6 to 11¼ in. deep from the 9th to the 28th of the month. In England and Wales snow was heaviest in Yorkshire and Lancashire and reached a level depth of 13 in. at High Mowthorpe, East Yorkshire, (574 ft.) and 12 in. at Habergham, Lancashire, (780 ft.) where there were drifts of 3 ft. at the station and 5-ft. drifts at 1,000 ft. nearby.

January 1956.—The first week was generally mild and dry, but on the 7th arctic air swept southwards to bring snow to much of Great Britain and falls became substantial as a depression formed in the North Sea. The second half of the month was milder and unsettled. In Scotland snow fell on 20–25 days in the north and 15–20 days in the south, and in the north and north-east the ground was covered almost continuously from about the 7th to the 31st, lying to a depth of 8–12 in. in many places on the 24th with drifts of 3–4 ft. In England and Wales snow fell in general on 7–15 days and was heaviest in north-east England and North Wales. On the 8th it lay 9 in. deep at High Mowthorpe (574 ft.) and 8–9 in. at Lincoln (22 ft.) where drifts of 4 ft. were reported. The depression which crossed the country on the 10th brought gales and widespread snow. Heavy continuous snow fell for 11 hr. in parts of Lincolnshire and lay to a depth of 15 in. Heavy falls of snow occurred on the

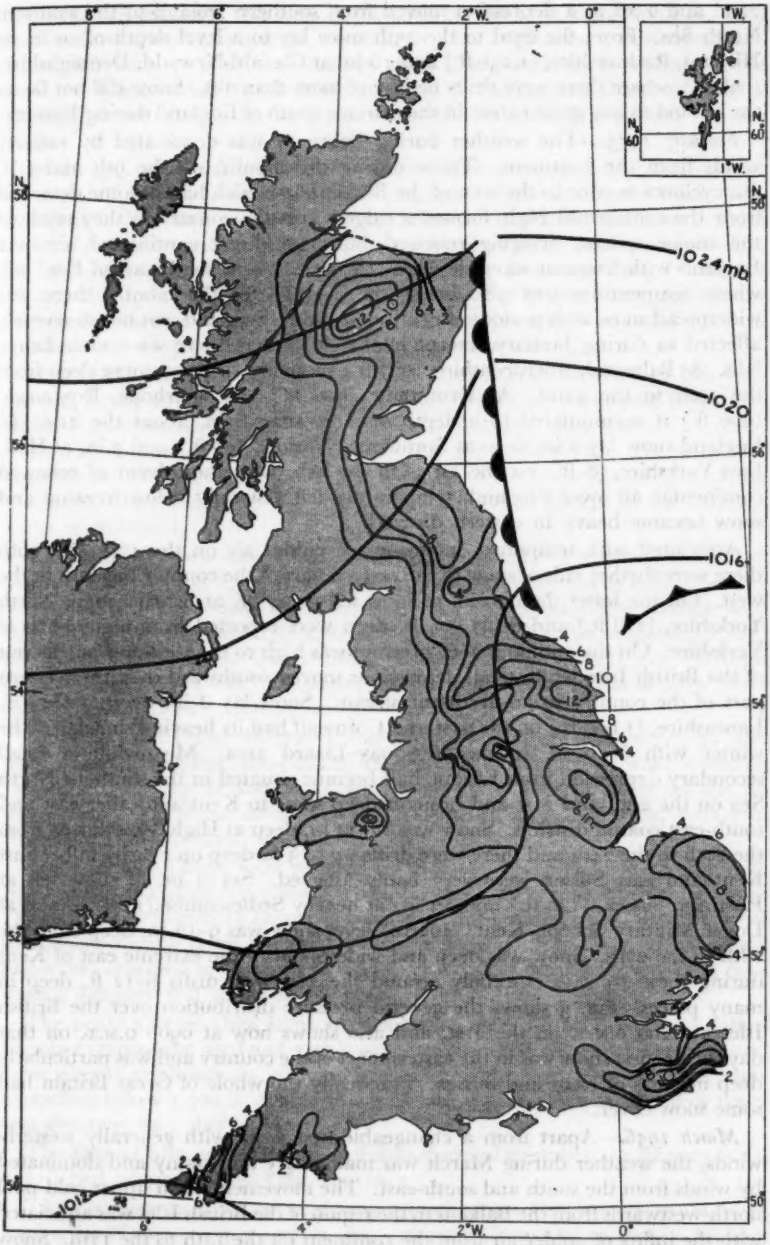


FIG. 3—SNOW DEPTHS AT 0900 G.M.T. AND PRESSURE DISTRIBUTION AT 1200 G.M.T., FEBRUARY 21, 1956

22nd and 23rd as a depression moved from southern Ireland to the southern North Sea. From the 23rd to the 25th snow lay to a level depth of 10 in. at Hirnant, Radnorshire, (1,250 ft.) and 18 in. at Clawdd-Newydd, Denbighshire, (998 ft.), where there were drifts nearby of more than 3 ft. Snow did not lie on the ground to any great extent in the extreme south of England during January.

February 1955.—The weather during February was dominated by easterly winds from the continent. Twice during the month, on the 9th and 21st, anticyclones over or to the west of the British Isles which had become detached from the continental high, formed a ridge across the country as they rejoined the major system, bringing renewed bursts of direct continental air over England with frequent snow showers. In the east and south-east of England, where temperature was 9°F. below the average for the month, there was widespread snow with periods of continuous frost. Scotland was not so severely affected as during January, except in the east where there were some heavy falls. At Balmoral, Aberdeenshire, (927 ft.) snow lay 10 in. or more deep from the 19th to the 22nd. At Drummuir (500 ft.) and Sourhope, Roxburgh, (900 ft.) it accumulated to a depth of more than 8 in. about the 21st. In England snow lay 2 in. deep at Sprowston, Norfolk, (93 ft.) and 7 in. at Hull, East Yorkshire, (8 ft.) on the 1st. On the 9th, with the advent of renewed continental air over England, temperature fell generally below freezing and snow became heavy in eastern districts.

Associated with temporary incursions of milder air on the 12th and 16th there were further falls of snow in the eastern part of the country but rain in the west. On the latter date 10 in. of snow fell in 24 hr. at Scarborough, North Yorkshire, (118 ft.) and drifts 3–4 ft. deep were reported from many parts of Yorkshire. On the 19th and 20th pressure was high to the west and north-west of the British Isles while small depressions moved southward over the western part of the country in an arctic air stream. Snow lay 8 in. deep at Cowpe, Lancashire, (1,000 ft.) on the 21st and Cornwall had its heaviest snowfall of the winter with 8–10 in. in the Newquay–Lizard area. Meanwhile a small secondary depression from Europe had become situated in the southern North Sea on the 20th and 21st and brought deep snow to Kent and other east and south-east coastal districts. Snow was 12–14 in. deep at High Mowthorpe from the 20th to the 24th and there were drifts up to 3 ft. deep on nearby hills. East Kent and east Sussex were very badly affected. Seven in. of snow fell at Hastings, Sussex, (149 ft.) and 13 in. at nearby Sedlescombe (170 ft.), and at Dover Military School, Kent, (402 ft.) level snow was 9–12 in. deep from the 18th to the 27th. Snow was deep and widespread in the extreme east of Kent during these 10 days especially around the 21st with drifts 6–12 ft. deep in many places. Fig. 3 shows the general pressure distribution over the British Isles at 1200 G.M.T. on the 21st, and also shows how at 0900 G.M.T. on that day the deepest snow was in the eastern part of the country and was particularly deep in parts of Kent and Sussex. Practically the whole of Great Britain had some snow cover.

March 1956.—Apart from a changeable first week with generally westerly winds, the weather during March was mainly dry and sunny and dominated by winds from the south and south-east. The movement of an upper cold pool north-westwards from the Balkans to the region of the British Isles was associated with the influx of colder air from the continent on the 14th to the 17th. Snow and sleet fell fairly widely in Scotland during this period and also during the

first week. Snow cover was usually thin, but on the 17th snow lay 5½ in. deep at Glenshee, Aberdeenshire, (1,100 ft.), 2–3 in. at Braemar, Aberdeenshire, (1,113 ft.) and 1 in. in the Dundee area. Snow was fairly widespread in northern England and north Wales around the 16th, and there were some scattered snow showers in these areas around the 4th, but little snow in the south.

April 1956.—An anticyclone was centred over or near to the British Isles for most of this dry, sunny but cold month. Light northerly winds predominated. In north and east Scotland snow fell on most days from the 2nd to the 18th and around the 26th. It lay to a depth of 2½ in. at Glenmore Lodge, Inverness-shire, (1,071 ft.) and at Achnagoichan, Inverness-shire, (1,000 ft.) around the 15th. In England and Wales snow occurred mainly around the 17th and 27th, but in general the snow-line was between 2,000 and 3,000 ft. and little snow lay at the level of the observing stations.

May 1956.—Pressure was high over the British Isles for most of this very dry and sunny month, though depressions passing to the north-west frequently affected extreme north-western districts. In Scotland snow fell on 11 days; it was most widespread on the 18th when a few snow showers were also experienced over some of the higher ground of northern England and the Midlands. The snow-line was mainly above 3,000 ft. except in the extreme north of Scotland.

Duration of snow cover on British mountains.—The mean number of days of snow cover at 2,500 ft. on four mountain groups used as indices was 97 compared with an average of 83 for the past nine seasons. The stations used were Glenbrittle (Cuillin Hills 3,300 ft.*), Meggernie Castle (mountains round Glen Lyon 3,400 ft.*), Capel Curig (Snowdonia 3,500 ft.*) and Tairbull (Brecon Beacons 2,800 ft.*). Diagrams showing the distribution of snow cover relative to height for 11 stations are given in Fig. 4.

Harris, in the Outer Hebrides, was snow covered on October 13–21 and 24–30, but was free from snow during the whole of November. It was covered on December 7–13, 17–21 and 26–30, on January 5–31 (except the 29th) and on February 13–25. Snow cover was also observed 2 days in March, 5 days in April and 1 day in May.

The Cuillins of Skye were covered on October 14–19 and 25–29 and were free from snow during November. They were covered almost continuously from December 7 to March 13 except January 2–4 and February 7–8. Reports were incomplete during April but the peaks were snow covered for 7 days in May. Snow was observed to be down to sea level on 6 days during December, 4 days during January and 1 day in February.

The peaks around Glen Lyon were snow covered during the second half of October (except the 23rd and 24th), were free from snow during November and were almost continuously covered from December 8 to April 20, the snow extending below 1,000 ft. during much of January and February. Snow cover was observed on 1 day in May.

The Paps of Jura were covered on 6 days during December, on January 6–14, 17–18 and 21–25 and on February 15–27.

The Cairngorms were covered continuously from October 13 to May 25 except for November 5–7 and 25–30, 4 days in December, 1 day in January

* These values are mean heights of the mountain groups.

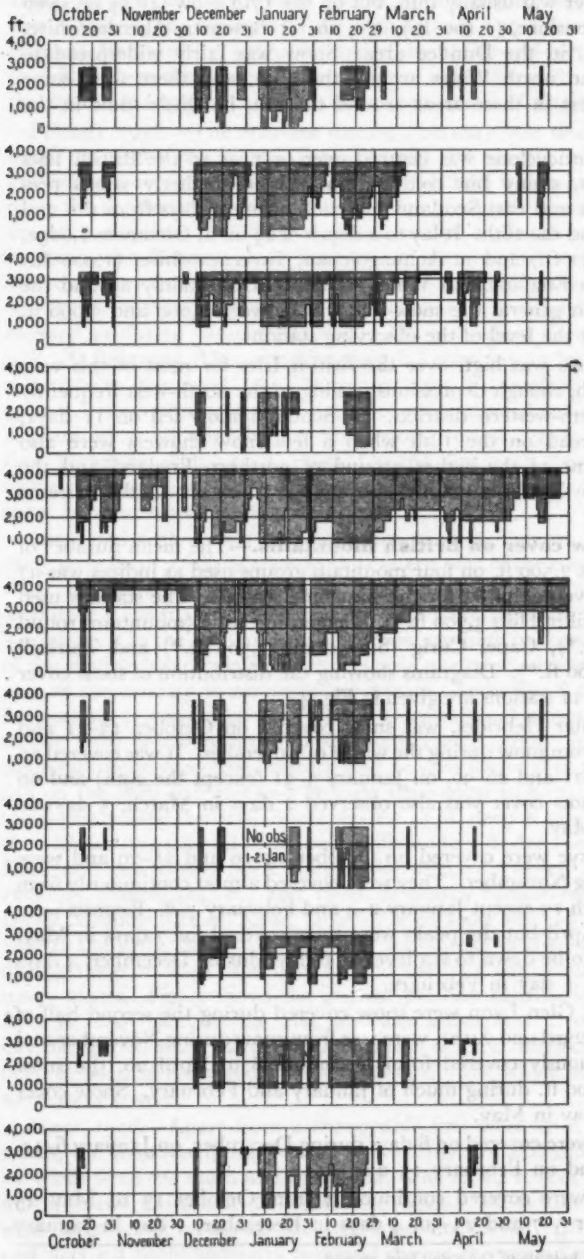

ft.
October November December January February March April May
10 20 31 10 20 30 10 20 31 10 20 31 10 20 29 10 20 31 10 20 30 10 20 31
4,000
3,000
2,000
1,000
0
No obs. 1-21 Jan.
CLISHAM and RONEVAL
Station: Leverburgh, Harris (Height: 25 ft.)
CUILLIN HILLS
Station: Glenbrittle Skye (Height: 30 ft.)
Mountains round GLEN LYON
Station: Meggernie Castle, Perthshire (Height: 760 ft.)
PAPS OF JURA
Station: Colonsay, Argyll (Height: 150 ft.)
CAIRNGORMS
Station: Achnagoichan, Inverness-shire (Height: 1,000 ft.)
BEN NEVIS
Station: Corpach, Inverness-shire (Height: 30 ft.)
SNOWDONIA
Station: Capel Curig, Caernarvonshire (Height: 700 ft.)
SOUTH SNOWDONIA
Station: Llanfrothen, Merionethshire (Height: 475 ft.)
BRECON BEACONS
Station: Tairbull, Brecknockshire (Height: 660 ft.)
CROSS FELL
Station: Alston, Cumberland (Height: 1,070 ft.)
HELVELLYN
Station: Patterdale, Westmorland (Height: 520 ft.)

FIG. 4—DISTRIBUTION OF SNOW COVER IN RELATION TO HEIGHT

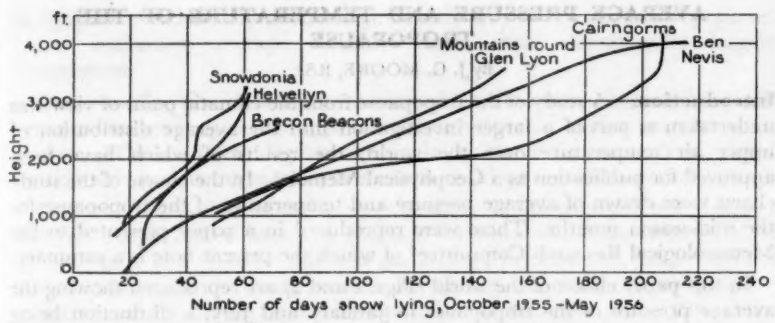


FIG. 5—SEASONAL DURATION OF SNOW COVER

and 2 days in May. Snow extended below 2,500 ft. from December 7–May 4 except for 5 days during the first week of January.

The summit of Ben Nevis was observed to be covered from October 13 until the end of the season except for November 30, December 27, January 28–30 and February 28. Snow extended below 3,000 ft. from December 8 until the end of the season except on the dates mentioned above when the summit was clear. Snow extended down to 1,000 ft. during the last three weeks of January and the first week and last two weeks of February except for the last three days.

The peaks near Capel Curig had snow cover above 3,000 ft. on 4 days during October, 8 days during December and from January 7 to February 27 except for January 8–9, 26–29 and February 2 and 5–8. Snow cover was also observed 2 days during March, 2 days during April and 1 day in May. Snow was reported down to sea level on most days during the third and fourth weeks of February.

The Brecon Beacons were snow covered at 2,500 ft. on December 12–26, January 8–February 28, and 3 days in April. Snow extended down to station level (660 ft.) on 1 day in December, 4 days during January and 10 days during February.

Cross Fell was snow-capped for 7 days in October, 13 days in December, from January 7 to February 27 (except February 4–8), on 6 days during both March and April and 1 day in May. Snow was observed down to station level (1,070 ft.) for much of the time from the second week of January until the end of February.

Helvellyn was snow covered for 2 days during October, 7 days during December, on January 7–15, 20–26 and January 30–February 26, and also 2 days during March and 4 days during April. Snow extended down to 2,000 ft. for most of this time, and down to station level (520 ft.) on 3 days during December, 9 days during January, 8 days during February and 1 day in March.

Curves showing the total seasonal duration at six stations are drawn in Fig. 5; 200 days snow cover was exceeded on Ben Nevis at 3,300 ft. and on the Cairngorms at 4,000 ft., 100 days cover was exceeded on the mountains about Glen Lyon above 2,300 ft. and 50 days on the Brecon Beacons, Helvellyn and Snowdonia at 2,000 ft., 2,300 ft. and 2,800 ft. respectively.

AVERAGE PRESSURE AND TEMPERATURE OF THE TROPOPAUSE

By J. G. MOORE, B.Sc.

Introduction.—A study of the tropopause from the climatic point of view was undertaken as part of a larger investigation into the average distribution of upper air temperature over the world, the results of which have been approved for publication as a Geophysical Memoir[1]. In the course of the study charts were drawn of average pressure and temperature of the tropopause for the mid-season months. These were reproduced in a paper presented to the Meteorological Research Committee[2] of which the present note is a summary.

In this paper charts of the world (Figs. 1 and 2) are reproduced showing the average pressure of the tropopause in January and July, a distinction being made between polar and tropical tropopauses. Charts are also reproduced (Figs. 3 and 4) showing for the same months, on circumpolar projection, the average pressure and temperature of the polar tropopause for the north polar region. An attempt has been made to delineate the region in which both polar and tropical tropopauses are found. The variation through the year of the monthly averages of pressure and temperature at the tropopause is also briefly discussed.

Definitions.—The tropopause marks the boundary between the troposphere in which the temperature falls more or less regularly with increasing height and the stratosphere where temperature rises or changes little with height.

Although the height of the tropopause, for the most part, increases from pole to equator, the tropopause itself is not, as was once thought, a continuous surface but comprises two clearly defined surfaces. These two surfaces, the high tropopause of equatorial regions and the lower tropopause of middle and high latitudes, extend poleward and equatorward respectively to overlap in the subtropics and form a region of two tropopauses. These are referred to as the tropical and polar tropopauses respectively. Even on average temperature-height curves for the subtropics two tropopauses are often shown quite clearly and, this being the case, it was thought necessary to distinguish between them when drawing the charts.

It was not possible to apply the same tropopause definition to all the available data. Many of the data were taken from publications of other meteorological services or received in manuscript with the mean values already evaluated. In such cases the tropopause definition used was generally unknown.

When the tropopause pressures and temperatures were extracted from individual daily ascents, the following definitions were used.

(i) The first tropopause is defined as the lowest level at which the lapse rate decreases to 2°C./Km. or less for at least 1 Km. above.

(ii) If in any higher layer the lapse rate exceeds 2°C./Km. for at least 1 Km., then a second tropopause above the first is defined by the same ruling as under (i).

A comparison between the results obtained from the above definitions and from those recommended by the World Meteorological Organization for trial

in 1954 showed that they differed significantly only at the tropical tropopause. Upon evaluating average monthly values these discrepancies largely disappeared.

Data used.—The data used were mainly radio-sonde observations made between the years 1940 and 1952 with observations for earlier years at a few stations. The number of years available at the different stations varied considerably and no attempt has been made to adopt a uniform period.

Charts.—The values of the average pressure of the tropopause in January and July are set out on Mercator charts of the world extending from 75°N. to 55°S. (Figs. 1 and 2). The values of the average pressure and temperature of the tropopause in the same months are shown on charts on circumpolar projection of the northern hemisphere between the pole and 55°N. (Figs. 3 and 4). Isopleths are drawn for intervals of 20 mb. of pressure for the polar tropopause and 10 mb. for the tropical tropopause. Isopleths of temperature for the polar tropopause are drawn at intervals of 4°C. Temperatures are given in degrees Absolute.

In regions where few data for the polar tropopause were available certain general principles were borne in mind: first, that unless there was strong evidence to the contrary, the isopleths should not diverge much from the mean wind flow of the middle troposphere, i.e. from the pressure contour lines, and secondly, that in temperate latitudes there is high positive correlation between the height of the tropopause and the temperature of the troposphere[2], and that pressure at the tropopause is therefore likely to be low over regions where the troposphere is relatively warm.

In equatorial regions, if data were insufficient, the isopleths were drawn largely by analogy with the temperature at 100 mb.

Over the greater part of the northern hemisphere the isopleths have been drawn with reasonable confidence in so far as their main features are concerned, except perhaps over the U.S.S.R. where the data available were very scanty. In the tropics although data were not numerous the values at different stations showed good agreement, and errors are therefore not likely to be large. Over the southern hemisphere, except in the region of Australasia, information was available for very few stations and little reliance can be placed on the lines.

Since the charts do not show values of average tropopause temperature for the whole world, the following table gives some indication of its distribution at latitudes south of 55°N. In these regions the distributions of average polar and tropical tropopause temperatures are mainly latitudinal.

Latitude	Average temperature of polar tropopause		Average temperature of tropical tropopause	
	January	July	January	July
	degrees Absolute			
40°N.	215	217	214	210
20°N.	...	...	194	199
0°	...	...	189	197

Region with two tropopauses.—In the subtropical regions of both hemispheres, roughly between latitudes 30° and 45°, two tropopauses are frequently indicated on the curves of ascent, but on some occasions there

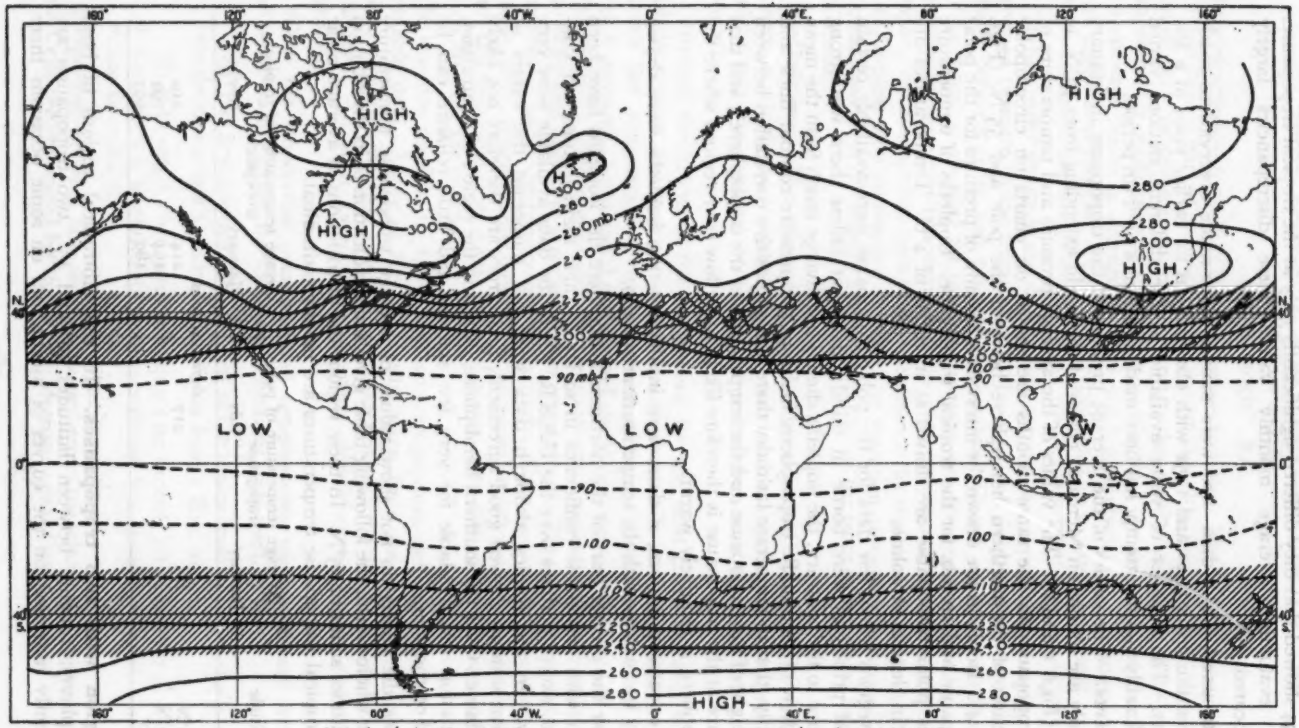


FIG. 1—AVERAGE PRESSURE OF THE TROPOPAUSE IN JANUARY

Areas in which frequencies of occurrence of both tropopauses are greater than 10 per cent. are shaded

FIG. 1—AVERAGE PRESSURE OF THE TROPOPAUSE IN JANUARY

Areas in which frequencies of occurrence of both tropopauses are greater than 10 per cent. are shaded

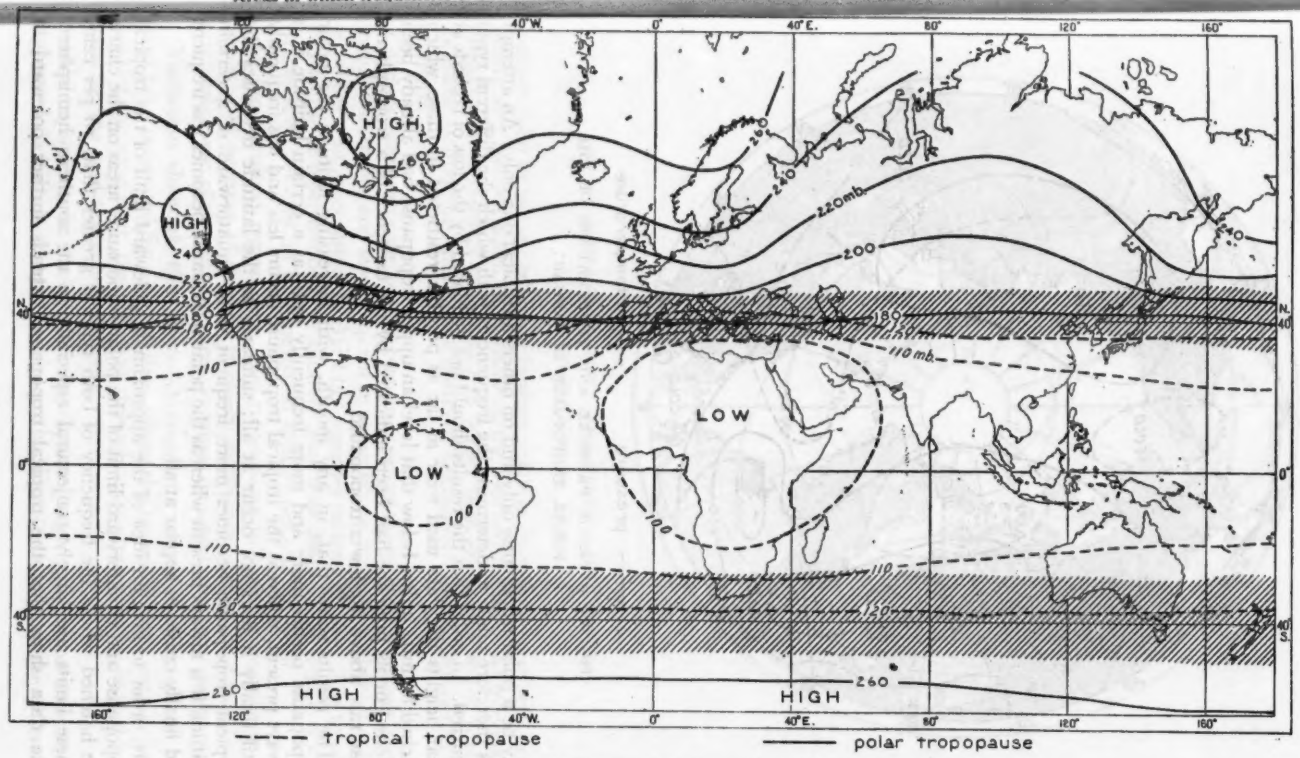


FIG. 2—AVERAGE PRESSURE OF THE TROPOPAUSE IN JULY

Areas in which frequencies of occurrence of both tropopauses are greater than 10 per cent. are shaded

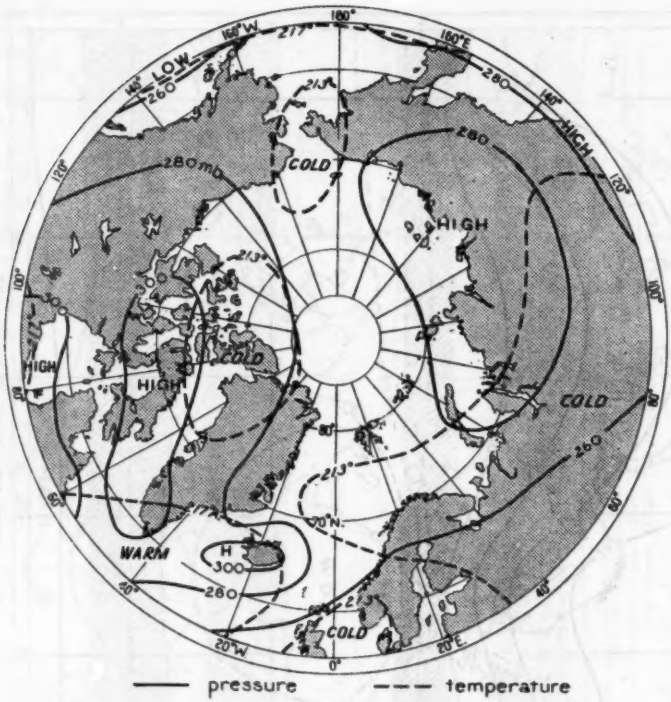


FIG. 3—AVERAGE PRESSURE AND TEMPERATURE OF THE POLAR TROPOPAUSE IN JANUARY

may be a polar tropopause only and on others a tropical one only. An attempt was therefore made to determine the frequencies with which the different types occurred. In order that the results should not be biased by the loss of records at great heights the data used were as far as possible restricted to those which reached 80 mb., unless below that level an upper tropopause had already been reached or its presence had been indicated by the existence of a tropospheric lapse rate above the lower tropopause.

The results show that, in any month, with increasing latitude the polar tropopause occurs more and more frequently until at a certain latitude it is always present, whereas the tropical tropopause occurs less and less frequently until finally it does not occur at all; similarly as the latitude decreases the tropical tropopause becomes more frequent until equatorward of a certain latitude it is always present whereas the polar tropopause becomes less frequent and finally ceases to appear at all.

In order to give an idea of the approximate poleward limit of the tropical tropopause and equatorward limit of the polar tropopause, areas on the charts are hatched where the frequency of both types is greater than 10 per cent. These limits are largely conjectural especially in the southern hemisphere. The data show that the tropical tropopause extends further poleward in

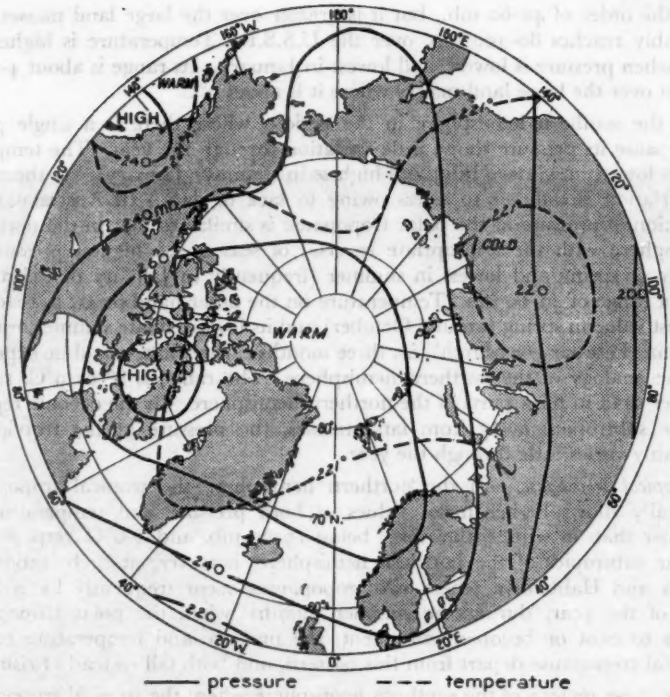


FIG. 4—AVERAGE PRESSURE AND TEMPERATURE OF THE POLAR TROPOPAUSE IN JULY

summer than in winter, reaching furthest north in July in the northern hemisphere and furthest south in January in the southern. The polar tropopause extends further towards the equator in winter than in summer but it reaches its lowest latitude in April in the northern hemisphere and in October in the southern.

At most stations in the zone of two tropopauses the polar tropopause is most frequent in spring and least frequent in summer, *e.g.* at Benina where it occurs on 78 per cent. of occasions in April but vanishes entirely in July. The tropical tropopause is most frequent in summer and least frequent in winter, *e.g.* at Gibraltar 80 per cent. in July compared with 45 per cent. in April.

In the transition regions from two tropopauses to a single tropopause the isopleths of pressure of the less frequent tropopause should be treated with reserve because of the relatively few occasions on which this tropopause exists.

Variation through the year.—Averages for all 12 months of the year have been computed for a few stations where the necessary data were avilable but, for the most part, the variation through the years has to be judged from data for the mid-season months only.

Polar tropopause.—In the northern hemisphere, in general, the pressure at the tropopause is highest in April and lowest in July. In most parts the difference

is of the order of 40–60 mb., but it is greater over the large land masses and probably reaches 80–100 mb. over the U.S.S.R. Temperature is highest in July when pressure is lowest, and lowest in January. Its range is about 4–6°C. except over the large land masses where it is about 9°C.

In the southern hemisphere in the regions where there is a single polar tropopause its pressure shows little variation through the year. The temperature is lowest in winter (July) and highest in summer (January), but the range of variation is difficult to assess owing to lack of data. In Australasia the variation of pressure at the polar tropopause is similar to that in the northern hemisphere with the appropriate reversal of season, *i.e.* highest pressure in winter or spring and lowest in summer (frequently in January or February) with a range of 40–60 mb. Temperature on the other hand seems to reach its highest value in spring (around October) and its lowest in late summer or early autumn (February or March), *i.e.* three months earlier than would be expected on the analogy of the northern hemisphere. The range is 8° or 9°C. rather greater than in most parts of the northern hemisphere. In the oceanic regions of the subtropics, away from land masses, the pressure at the tropopause probably varies little through the year.

Tropical tropopause.—In the northern hemisphere the tropical tropopause generally shows higher mean values of both pressure and temperature in summer than in winter, the range being 15–20 mb. and 4–6°C. respectively. In the subtropics of the northern hemisphere, however, at such stations as Malta and Habbaniya where two tropopauses occur frequently for a large part of the year, during the summer months, when the polar tropopause ceases to exist or becomes infrequent, the pressure and temperature of the tropical tropopause depart from this pattern, and both fall instead of rising.

For those regions of the southern hemisphere where the tropical tropopause occurs frequently throughout the year, the few data available indicate that the annual variation of the pressure at the tropopause is less pronounced than in the northern hemisphere. With a range of 10–15 mb. the monthly mean tropopause pressure reaches its highest value in winter or spring and lowest in summer or autumn. Temperature shows a range of 6–8°C. with highest values in spring and lowest in summer or autumn.

REFERENCES

1. GOLDIE, N., MOORE, J. G. and AUSTIN, E. E.; Upper air temperature over the world. *Geophys. Mem., London* (in preparation).
2. MOORE, J. G.; Average pressure and temperature of the tropopause. *Met. Res. Pap., London*, No. 874, 1954.
3. DINES, W. H.; The characteristics of the free atmosphere. *Geophys. Mem., London*, **2**, No. 13, 1919.

AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE NORTH POLAR REGIONS IN JANUARY

By H. HEASTIE, M.Sc.

Introduction.—*Geophysical Memoirs* No. 85 "Upper winds over the world"[1] includes seasonal charts of the average heights of the isobaric surfaces 700, 500, 300, 200 and 130 mb. These charts were necessarily based on data for earlier years when the network of upper air stations was, in most parts of the world, extremely sparse. All available data were used irrespective of period, but the approach had still to be largely statistical. It was realized at the

[*To face p. 368*

Ilford F.P.3. 1/50th sec., f5.6, orange filter. *Reproduced by courtesy of D. O. Booth*

STORM CLOUD IN THE INDIAN OCEAN

This photograph was taken on July 24, 1955 between 6.00 and 6.30 p.m. from H.M.S. *Asturias* almost midway between Singapore and Colombo. This was the beginning of the storm cloud building up from the west during a monsoon period, and the storm which lasted almost 48 hr., although not terribly severe, brought torrential rain for several hours at a stretch during this period. The swell was quite considerable as we had to alter course to counteract the list and the roll, and the waves rose quite frequently to a height of 40 ft. and crashed over the bows to reach the bridge. The previous day, before the storm, had been unusually calm.

D. O. BOOTH

Photograph reproduced by courtesy of K. E. Woodley

1800 G.M.T.

Photograph reproduced by courtesy of K. E. Woodley

1802 G.M.T.

CIRRIFORM CLOUD AT RICHMOND, JULY 8, 1956

These photographs were taken looking west-north-west

(see p. 374)

Photograph reproduced by courtesy of K. E. Woodley

1806 G.M.T.

Photograph reproduced by courtesy of K. E. Woodley

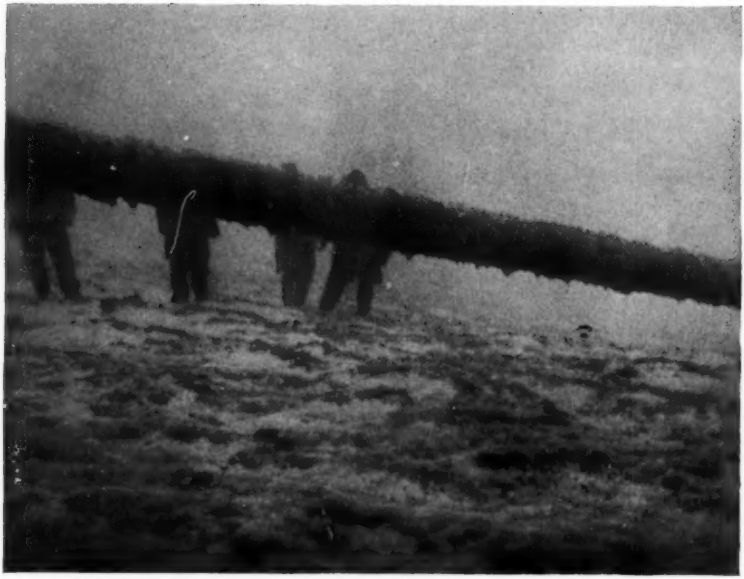
1807 G.M.T.

ALTOCUMULOUS CLOUD AT RICHMOND, JULY 8, 1956

These photographs were taken looking north-west

(see p. 374)

To face p. 369]



Reproduced by courtesy of the North of Scotland Hydro-Electricity Board

Reproduced by courtesy of the North of Scotland Hydro-Electricity Board

ICING ON AN ELECTRIC POWER LINE IN THE GRAMPIANS

The photographs are of icing on the bottom conductor over Lecht and were taken at 1500 G.M.T., March 21, 1956

(see p. 376)

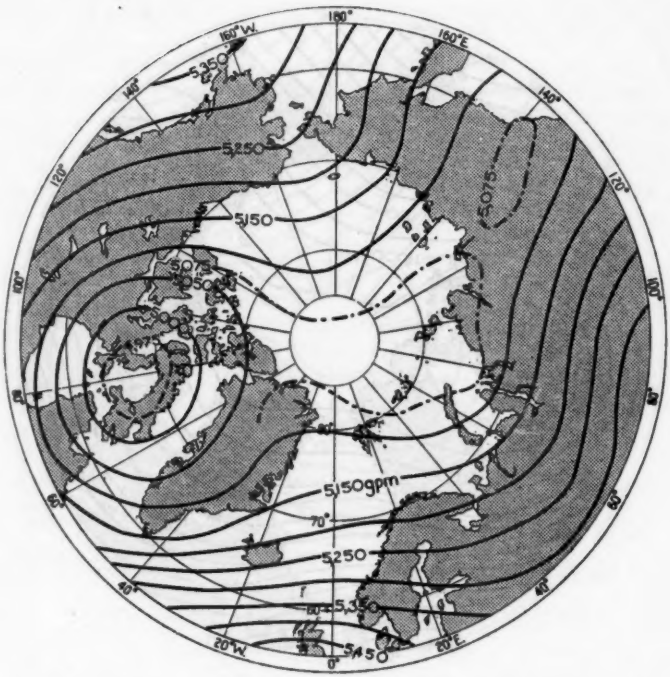


FIG. 1—AVERAGE 500-MB. CONTOUR HEIGHTS, JANUARY 1949–53

time of publication that these charts would need revision and, by about 1953, the increasing number of upper air data available made such a revision feasible.

The charts in *Geophysical Memoirs* No. 85 are on a Mercator projection and do not extend beyond 75°N. Therefore, in view of the increasing importance of the polar regions for aviation, it was decided to start the revision by constructing circumpolar charts for the standard isobaric surfaces. The charts of the original Memoir apply to the four seasons, each of three months. However, changes within a season can be very marked and, to obviate the difficulty of maintaining equal weighting all over the chart for each month of the season, the charts were to be drawn for the mid-season months—January, April, July and October. This procedure also enables the full seasonal changes to be shown more clearly. Further, attention was to be confined to a fixed period rather than to one varied to include earlier years in particular areas. The five-year period 1949–53 was chosen, mainly because January 1949 marked the beginning of both regular CLIMAT-TEMP data and publication by the meteorological service in western Germany[2] of monthly mean 500-mb. contour charts for a large part of the northern hemisphere. Finally it was decided to extend the range to 100 mb. and to include a chart for 150 mb.

This paper presents some of the circumpolar average contour charts for January and a brief discussion of their preparation. Details of the method are given elsewhere[3].

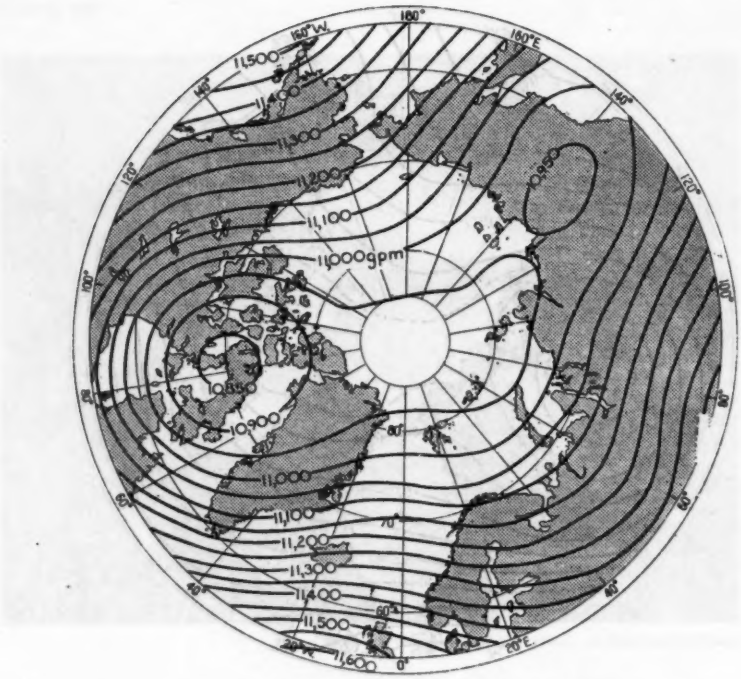


FIG. 2—AVERAGE 200-MB. CONTOUR HEIGHTS, JANUARY 1949–53

Data.—A CLIMAT-TEMP report provides monthly mean values of the contour height and temperature of the standard isobaric surfaces up to 200 mb. and the CLIMAT-TEMP reporting stations give a reasonable network of data except over the U.S.S.R. and eastern Europe. Over this area (and particularly Siberia) the German monthly mean contour charts were used to supplement the very sparse Russian data. These German charts were used since reference to the corresponding daily charts suggested that more data from the U.S.S.R. were available in Germany than in Great Britain.

The main sources of data used in the preparation of the charts were the CLIMAT TEMP reports and the data tabulations from United States Weather Bureau *Daily series synoptic weather maps*. These were supplemented by data on micro-film supplied by the Statens Meteorologisk-Hydrografiska Anstalt, Stockholm and Det Norske Meteorologiska Institutt, Oslo and by manuscript data supplied by the United States Weather Bureau and the Canadian Meteorological Service. The *Daily series synoptic weather maps* for January 1953 were not available, so for this month data were extracted from the synoptic charts of the Central Forecasting Office, Dunstable, and all Russian data received there were examined.

Method of constructing the charts.—Very few stations were available with equal reliability for all five years, particularly above 200 mb., and it proved necessary to construct a separate set of charts for each year in order to

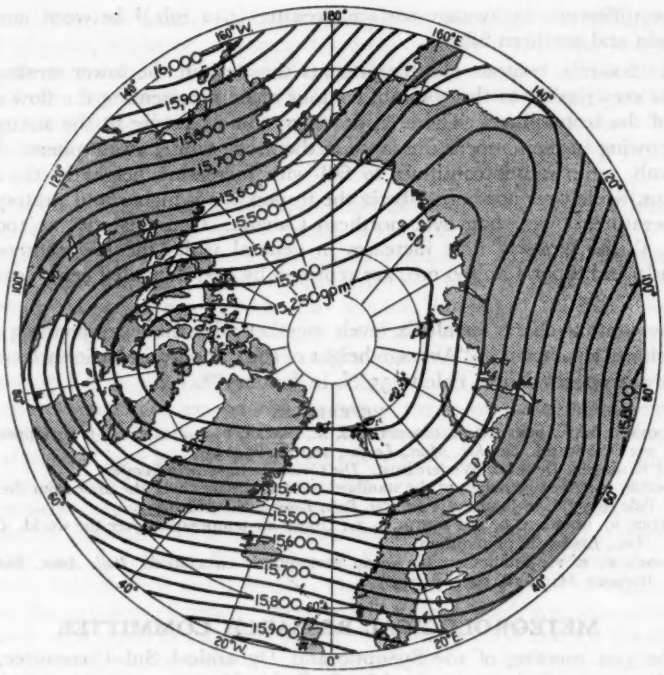


FIG. 3—AVERAGE 100-MB. CONTOUR HEIGHTS, JANUARY 1949–53

make the best use of the available data. The data from Siberia were particularly sparse and the 500-mb. contour charts were drawn first so that assistance in drawing this area could be obtained from the monthly mean 500-mb. contour charts published in the monthly supplement to the *Täglicher Wetterbericht*. The charts for the other levels were then constructed by drawing the thickness charts for the various layers 700–500 mb., 500–300 mb. etc.

Over the U.S.S.R. no useful data were available above 300 mb. and the average thickness charts were extended over this area by constructing a chart of average 300-mb. temperature and using temperature lapse rates derived from charts of average temperature of standard isobaric surfaces[4]. For the layer containing the tropopause a "correction for tropopause" was evaluated by using charts of average temperature and pressure at the tropopause[4].

Charts.—Three only of the charts are illustrated here. The 500-mb. contour chart (Fig. 1) represents the flow pattern in the troposphere. Three main troughs are indicated at about 55°E., 135°E. and 80°W. The two low centres, one to the north of Hudson Bay and the second, a composite low over northern Siberia, correspond very closely to the two centres of low tropopause on the tropopause pressure charts[4]. The pattern of flow at 700 mb., 300 mb. and 200 mb. (Fig. 2) is very similar to that at 500 mb. while the strength of flow increases with height. The contour height difference (*c.*100 m.) between the two low centres remains practically constant, and, indeed, is a reflection

of the difference in average surface pressure (*c.*12 mb.)[5] between northern Canada and northern Siberia.

The 200-mb. contour chart represents the flow in the lower stratosphere and is very similar to the 300-mb. contour chart representing the flow at the top of the troposphere. There is, however, some increase in the strength of flow, owing to the temperature lapse in the arctic winter stratosphere. Above 200 mb. temperature continues to fall with increasing height in the arctic regions, while over northern Siberia the tropopause is higher and stratospheric temperatures lower than over northern Canada. Consequently, at 100 mb. (Fig. 3) the westerly flow increases in general while the low centres over Canada and Siberia at 200 mb. are replaced by one elongated centre over the pole.

The contour charts for all six levels together with the corresponding thickness charts are shown in "Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January"[3].

REFERENCES

1. BROOKS, C. E. P., DURST, C. S., CARRUTHERS, N., DEWAR, D. and SAWYER, J. S.; Upper winds over the world. *Geophys. Mem., London*, **10**, No. 85, 1950.
2. Bad Kissingen, Deutsche Wetterdienst. *Die Grosswetterlagen Mitteleuropas.*
3. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January. *Met. Res. Pap., London*, No. 918, 1955.
4. GOLDIE, N., MOORE, J. G. and AUSTIN, E. E.; Upper air temperature over the world. *Geophys. Mem., London* (in preparation).
5. BROOKS, C. E. P.; Studies on the mean atmospheric circulation. *Bull. Amer. Met. Soc., Worcester Mass.*, **18**, 1937, p. 313.

METEOROLOGICAL RESEARCH COMMITTEE

At the 31st meeting of the Synoptic and Dynamical Sub-Committee, held on May 31, 1956 the paper by Mr. R. F. M. Hay[1] on variations of air and sea temperature in short periods of time at the ocean weather stations I and J in 1948–52, including factual information and deductions therefrom, gave rise to discussion on the constituents of the energy exchange at the sea surface. The Sub-Committee hoped that this pioneer study would be the starting point for other investigations in the same field. Mr. D. H. Johnson[2] described experiments made in the Meteorological Office on the objective analysis of 500-mb. pressure contour charts with the aim of greatly reducing the time required in preparing such charts (by conventional methods) prior to their use in production of forecast charts by the numerical-prediction (electronic computer) technique. The method tried consisted in finding, by least squares, a quadratic or cubic surface, which gave the best fit to observed contour heights and winds at a group of upper air stations, and results obtained were held fully to justify further work on these lines. The third of a series of reports on the harmonic representation of the annual temperature variation was presented by Mr. J. M. Craddock[3]. The report gives, for 160 stations in the British Isles, the temperature normals in the form of the parameters in a two-term harmonic. During discussion on the distribution of the amplitude and phase over the area the author said that he hoped to deal later with the physical causes of prominent features of the annual variation in temperature. Mr. J. K. Bannon[4] described his attempt to reduce the irregular variations in the mean monthly pressures at the tropopause (and corresponding temperatures at a number of levels) at Lerwick and Larkhill 1942–53, on the basis of the values of mean-sea-level pressures for the longer period 1900–39. In the discussion, a suggestion

was made that the annual variation of upper air data, for a relatively short period of years, might be represented satisfactorily by a two-term harmonic. In the discussion on Mr. H. Heastie's paper[5] which is a sequel to *Met. Res. Pap.* No. 918 dealing with the average height of isobaric surfaces in January, the comment was made that it is rather surprising that at high levels there should be symmetry of thickness patterns about the pole but asymmetry in the pressure contour-height pattern.

At the 22nd meeting of the Instruments Sub-Committee, held on June 19, 1956 the development of a vertical gustiness recorder described by Mr. J. I. P. Jones[6] and simultaneous records recently obtained at three heights were noted with very great interest. The technique will yield valuable data for the study of atmospheric turbulence up to heights of a few thousand feet. Discussion on the characteristics and performance of particular lithium chloride dew-point hygrometers as used in the London area[7] and by the British North Greenland Expedition[8] led to suggestions on the possibility of using other hygroscopic substances in order to extend the humidity range of these instruments at temperatures well below −20°C., and on the desirability of increasing the thermal load. There is need for further investigation on the determination of humidity at very low temperatures. Mr. M. J. Blackwell[9] reported the improvements which have been achieved in the new version of the daylight illumination recorder and in its calibration and maintenance. It is proposed to install the new form of recorder at Kew Observatory, Victory House (London), Eskdalemuir and Lerwick. Consideration was given to various aspects of the problem of measurement of the surface wind, *e.g.*, correction of measured wind speed to standard height above the ground and for the effects of site exposure, and the horizontal interpolation of wind from satisfactory measurements obtained at places a considerable distance apart. Reference was made to requirements for specialized information on air flow near the surface in relation to building, farming and forestry activities. The possibility of undertaking field experiments for further investigation of these problems is to be examined.

ABSTRACTS

1. HAY, R. F. M.; Some aspects of variations of air and sea surface temperature in short periods at ocean weather stations I and J of significance to the synoptic climatologist. *Met. Res. Pap., London*, No. 949, S.C. II/201, 1956.

The abstract of this paper will be published later.

2. JOHNSON, D. H.; Objective analysis. *Met. Res. Pap., London*, No. 965, S.C. II/207, 1956.

Time would be saved by machine calculation of a contour height as a quadratic function of geographical co-ordinates, obtained by fitting a least-squares solution to observed heights and winds suitably weighted. This paper describes preliminary computations using a six-station network over the British Isles and a five-station network, mainly of weather ships. A cubic surface was also tried. Further work is described by F. H. Bushby in *Met. Res. Pap.*, No. 986, 1956.

3. CRADDOCK, J. M.; The harmonic representation of the annual temperature variation in different parts of the British Isles. *Met. Res. Pap., London*, No. 970, S.C. II/208, 1956.

In continuation of *Met. Res. Pap.* No. 915 the mean annual temperature 1921–50 and the phase and amplitude of the first and second harmonics, calculated from the monthly means, are given and plotted for 160 stations in the British Isles. The phase of the second harmonic is shown by the number of days its maximum falls after that of the first.

4. BANNON, J. K.; Long-period averages for the upper air. *Met. Res. Pap., London*, No. 978, S.C. II/209, 1956.

Average monthly tropopause pressures and temperatures and temperatures at 100, 150, 200, 300, 500 and 700 mb. at Larkhill and Lerwick are given for 1942–53. Estimated values for 1900–39 are calculated from regression equations on surface pressures, resulting in a smoother

annual variation. The values are also shown graphically, including extremes of pressure and standard deviations at the tropopause.

5. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in July. *Met. Res. Pap., London*, No, 981, S.C. II/210, 1956.

In continuation of M.R.P. 918, circumpolar charts for standard pressure levels are given for July 1949–53, for 700, 500, 300, 200, 150 and 100 mb. and intervening thicknesses. They show marked differences from January, especially an asymmetric mainly westerly flow over Eurasia, increasing with height, and extending across the pole to give easterly winds over northernmost Canada and Greenland.

6. JONES, J. I. P.; A vertical gustiness recorder for use with a captive balloon. *Met. Res. Pap., London*, No. 974, S.C. I/113, 1956.

This lightweight instrument consists of a balsa wood and tissue paper inclination vane which actuates a potentiometer, and a windmill-type anemometer, at either end of a suspended arm damped to prevent oscillation. Ground recording is electrical. Photographs, wiring diagrams and specimen records are shown.

7. MACDOWALL, J.; An electrical dewpoint hygrometer suitable for routine meteorological use. *Met. Res. Pap., London*, No. 977, S.C. I/114, 1956.

A hygrometer suitable for continuous recording of dew point (resembling that of J. H. Conover) is described and illustrated. It consists of a varnished brass tube covered with glass tape impregnated with lithium chloride and wound with two parallel silver wires. Operation and comparison with an Assmann psychrometer are described; accuracy is better than ± 3 per cent.

8. HAMILTON, R. A.; The measurement of humidity at Britannia Se 1952–53. *Met. Res. Pap., London*, No. 983, S.C. I/115, 1956.

The hygrometers used by the British North Greenland Expedition at Britannia Se (77°9′N. 29°36′W.) for measuring humidities at low temperatures were dry-bulb and wet-bulb, hair hygrometer and lithium chloride hygrometer. Comparisons between these are set out in a number of tables and standard errors given. Calibration of the lithium chloride hygrometer is plotted.

9. BLACKWELL, M. J. and POWELL, D. B. B.; On the development of an improved daylight illumination recorder. *Met. Res. Pap., London*, No. 988, S.C. I/116, 1956.

The faults of the present Mk. II instrument at Kew include a temperature coefficient, cosine-law response, spectral sensitivity and unequal illumination of diffusing plate. An improved Model Mk. III is described in which these are corrected. Comparisons between Mk. II and III are given.

LETTERS TO THE EDITOR

Unstable cloud layer

During the seven min. between 1800 and 1807 G.M.T. on Sunday, July 8, 1956, four photographs were taken at Richmond, Surrey, of a large cloud patch developing from a fine structure, almost cirriform in appearance, into alto-cumulus floccus. The first two photographs [in the centre of this magazine] were taken looking approximately west-north-west within a minute or so of each other and show the sheet increasing whilst still consisting of small cloudlets. The second pair of photographs show the same cloud sheet some five min. afterwards, the camera then having been swung round to approximately north-west. The whole of the cloud patch had by then turned into well broken floccus. This drifted away north-eastwards gradually dissipating, the sky becoming almost cloudless. No further photographs were possible.

The rate of progress of the cloud in its fine-structure state left doubts that the advance was genuine movement, especially when the comparatively slow movement away of the cloud when in its floccus state was taken into account. It is probable, therefore, that most of the apparent advance in the leading edge was due to rapid formation of the cloud.

K. E. WOODLEY

Harrow, July 18, 1956

[At 1800 G.M.T. on July 8 a depression was centred about 100 miles north-west of Ireland. There was a large warm sector, the warm front running eastwards across the north of Scotland to the Heligoland Bight and the cold front southwards to the Bay of Biscay. Pressure was almost uniform from central England to southern France. The air in the rear of the cold front was much colder than that in the warm sector at all levels. The cold front reached the London area at about 0600 G.M.T. the following day. Heavy thunderstorms occurred over south-east England during the night of July 8–9 and were particularly heavy in the early morning.—Ed., *M.M.*]

Speed of warm fronts

The *Meteorological Magazine* for August 1955 contains an important note by C. H. Hinkel and W. E. Saunders, who found that on the Atlantic warm fronts move at an average speed of five-sixths of the geostrophic value, compared with the two-thirds which has been accepted as normal both in the British Isles and North America. This difference is unexpectedly large, and must be important for forecasting, considering that the difference in position after 24 hr. must often exceed 100 miles. Now that the figures have been available for about a year, it would be interesting to know how they are interpreted. The authors mention frictional drag as the most probable explanation and this is the only obvious difference between a sea and a land surface. Nevertheless if this is a complete explanation there are points of difficulty. Frontal analysis has always aimed at independence of very shallow cold layers, even when upper air information was scanty. Most warm fronts over western and central Europe are drawn to fit the isobaric troughs. Are we to infer that the trough is commonly held back 100 miles or more by surface friction?

The combination of surface friction with other factors may be worth considering. Just ahead of a warm front there is a strong thermal wind parallel to it and under such conditions turbulence originating on the ground may influence the wind up to a greater height than normal. Another factor liable to influence the effective movement of a warm front is a strong forward shear a few thousand feet above it, due to a non-frontal thermal wind, combined with rapid surface heating of the shallow cold air just ahead of the front. On the whole this process is most effective over the sea, especially if the existence of precipitation or clouds determines the retention of a weakening front in some marginal cases.

On the whole it appears that friction comes into the problem and that quasi-geostrophic dynamical theory cannot explain the whole of the ageostrophic motion of fronts. This last point receives some support from Table III of the recently published *Geophysical Memoir* No. 98.

C. K. M. DOUGLAS

Set Fair, Beer, Devon, July 17, 1956

[With regard to the question raised in the first paragraph of Mr. Douglas's letter, the fronts were placed using the normal surface properties of warm fronts. This implies that account is taken of shallow cold layers. There seems no reason why the trough should not tend to get ahead of the surface front and presumably this is what sometimes occurs over land.

Of the two factors mentioned in the second paragraph, the second one seems largely to have been ruled out by the criteria of selection of the fronts used in

the investigation, though it might be effective with weaker fronts which were excluded because they were not considered to be sufficiently marked.

We are inclined to the view that a combination of friction and turbulence would appear to be the most likely cause. We feel, however, that a very much more detailed study, than that undertaken, would be necessary for a definite conclusion to be reached.

Forecasting practice has provided many examples of the operation of the the "five-sixths rule" over the North Atlantic and we have no reason to doubt the genuineness of the result.—W. E. SAUNDERS and C. H. HINKEL.]

NOTES AND NEWS

Icing of overhead high-voltage electric power lines in the Grampians

During previous winters, electric power failures due to icing of lines had occurred on several occasions on two particular stretches of line in the Grampians. During the past winter a careful watch was kept on weather conditions in this area and a record of failures certainly or possibly due to icing maintained. There was one failure possibly due to icing and two certainly due to icing, all occurring within a three-day period although weather conditions made icing a decided risk on many occasions.

The sections of line considered were Fort Augustus to Laggan Bridge which goes through the high pass of Corrieyairick, rising to 2,507 ft. above sea level, and from Cock Bridge to Tomintoul through the high pass of the Lecht rising to a height of 2,170 ft. Both these high passes run roughly at right angles to most of the valleys in the area which run from south-west to north-east parallel to the Great Glen, so that even at such a height there is shelter which makes assessment of cloud base in the area extremely difficult.

During the period March 19 to March 21, 1956, when the failures were reported, the area was affected by a south-easterly air stream. East coast areas of Scotland had complete cover of stratocumulus with extensive low stratus underneath with base below 1,000 ft. Cloud base rose gradually to the west, due to drying out in passage over the mountains, and cloud was well broken in west coast areas. The main top of the cloud was of the order of 4,000—5,000 ft. and freezing level remained between 1,000 and 2,000 ft. until the 21st when it rose to nearly 5,000 ft. with a change of air mass preceded by a belt of mainly slight precipitation. Up to this time there had been only negligible amounts of precipitation, usually local light drizzle. The drizzle became moderate at Glenlivet (1,075 ft.) with cloud on or near the ground just before 1800 G.M.T. on the 20th and these conditions (confirmed at 2100 G.M.T.) probably persisted through the night, drizzle changing to rain between 0600 G.M.T. and 0900 G.M.T. on the 21st. The total fall in this spell of rain and drizzle was 2·6 mm. Temperatures at Glenlivet in the period up to 0900 G.M.T. on the 21st varied from 31° to 38°F. rising to 41°F. on the 21st. Winds were mainly E. to SE., rarely falling below 10 kt. and occasionally reaching 20 kt.

The failures were as follows:—

March 19.—At 0018 G.M.T. the Fort Augustus–Laggan Bridge line failed, presumably due to ice loading reducing working clearances, but the line was restored five minutes later and there was no permanent damage so that it is not certain that the interruption was due to ice.

March 20.—One of the lines over the Lecht failed at 1905 G.M.T. This was due to clashing and burning of the conductors probably caused by oscillation after shedding of ice load and excessive sag due to conductor slip at the suspension clamps on the Lecht summit. Radial thickness of the ice on bare conductor at 0930 G.M.T. on the 20th was 2½ in. and on one of the conductors which had been covered with a skin of poly-vinyl plastic about $\frac{1}{16}$ in. thick was 3 in. This line was out of action until the 23rd, having two broken conductors right on the Lecht summit.

March 21.—The second line over the Lecht (conductors carried on opposite side of pylons) failed at 0148 G.M.T. but was restored at 0241 G.M.T. so that at that time there were no conductors in contact with each other or with the earth. The fault may have been due to shedding of ice causing a conductor to oscillate and contact another conductor. The line failed again at 0737 G.M.T. and once more there were two broken conductors right on the Lecht summit. (See photographs facing p. 369)

The following is a careful description of the icing, provided by the Aberdeen area Manager:—

> "The ice on spans 429–431 was almost truly radial and 6 in. in diameter and caused the bottom AF (Aberdeen/Fort Augustus) conductor to sag very low. The ice had a solid core, becoming porous and less dense at the surface, and was much darker in colour than the ice seen on any previous occasion. It is worth noting that the above deposits were formed in the presence of thick mist at freezing temperature and a light easterly wind. So far as I am aware, all previous ice deposits causing outages were formed in the presence of sleet in high winds. The resulting effects from these two causes of ice formation confirm that "fog" ice deposits are the heaviest. You will recollect that on February 16, 1955 when the conductors were loaded with elliptical ice formation 9 in. across by 7 in. down, deposited by wind-borne snow, the bottom conductor was roughtly 18 ft. above ground level.
>
> At 2020 G.M.T. on March 20, we telephoned the proprietors of the Allargue Hotel, Corgarff, (south of the Lecht summit) for a weather report, and this was given as "freezing—thick mist—light easterly wind".
>
> You will no doubt be aware that the severest ice deposits occurring in the past on the Lecht section have been on spans between towers 429 and 432, which lie approximately 2,170 ft. and 1,930 ft. respectively above sea level.

It is probably significant that the lowest cloud reported at Glenlivet (1,075 ft.) which is on the lee side of the Lecht was consistently 1,300–1,400 ft. (i.e. 2,400 ft. above sea level) throughout the 19th and on the 20th up to and including 1500 G.M.T. Between 1200 and 1500 G.M.T. the wind backed from SE. to E. and this was probably responsible for the low stratus creeping up the Don Valley to the Lecht summit and into Glenlivet between 1500 and 1800 G.M.T. It is possible that the Lecht summit was not in cloud on the 19th and early 20th; if so deposition of rime must have been remarkably fast and judging from the appearance must have been deposited from the surrounding cloud in quiet conditions, sheltered from wind, because of the circular cross-section.

Tentative conclusions to be drawn from the winter's records are that, because of shelter effects, the worst icing conditions, associated with icing in shower cloud, do not often affect the lines long enough to cause serious icing but that serious icing can occur in freezing cloud of the layer type when this penetrates into the high passes. The fact that temperatures were only just below freezing may be important in determining the relative rate of deposition in these circumstances.

The author is indebted to Mr. N. B. Macarthur, System Operation Engineer,

Pitlochry for much of the information on which the article is based and to the North of Scotland Hydro Electric Board for permission to publish this.

P. E. PHILLIPS

REVIEWS

The generation of electricity by wind power. By E. W. Golding. Spon's electrical engineering series. 8¾ in. × 5¾ in., xviii + 318, *Illus.* E. and F. N. Spon Ltd., London, 1955. Price 50*s*.

Whether the generation of electricity by wind power would, or would not, be economic depends not only on the average wind over a long period, but also on how the wind fluctuates about the average. The dependence upon the wind fluctuations is three-fold: first, wind eddies which are small compared with the size of the windmill rotor may result in unbalance, and the rotor and control gear must be sufficiently robust to withstand the consequent stresses; second, since the output from a wind turbine varies as the cube of the wind speed (assuming constant efficiency) the total output in a fluctuating wind, $k\int v^3 dt$, is affected by the size and nature of the fluctuations; third, the fluctuations in output which result from fluctuations in wind speed may carry an economic penalty.

The smaller eddies, those which lead to stresses in the rotor, are difficult to measure and their importance difficult to assess. Golding states that eddies smaller than 10 ft. across are not significant in this connexion. Arguing that in a 70 m.p.h. wind (the strongest in which a wind turbine is likely to have to operate) an eddy of this size would pass a fixed point in about 1/10 sec., Golding deduces that an anemometer with a response time of this order is required if these eddies are to be studied, and a special "gust anemometer" was developed by the Electrical Research Association for this purpose. Since changes in wind direction, and also deviations from the horizontal, may be as important as changes in speed, three types of anemometer were developed; for the measurement of (*a*) horizontal component of wind velocity without regard to direction; (*b*) velocity components in two directions at right angles; (*c*) vertical components. Meteorologists will be disappointed that, apart from reproducing one or two traces from the first of these types, no information is given about the results obtained. Meteorologists will also wonder whether Golding is altogether justified in ignoring, as he does, the time factor. An eddy which is 10 ft. across will take, as has been said, something like 1/10 sec. to pass the turbine blades. Is this long enough to do any damage? It is usually considered that for ordinary buildings mean winds over a period of about a minute are what matter. Could an eddy lasting only 1/10 sec. do any damage to the rotating blades of a wind turbine?

Rather larger eddies are of importance because they affect the output from the generator. Since $\int_0^T v^3.dt/T$ is always greater than $\left[\int_0^T v.dt/T\right]^3$, the total output in a fluctuating wind (assuming constant efficiency) is always greater than the output from the mean wind—and the greater the fluctuations, and the lower the mean wind, the greater this difference usually is. In assessing

the total output from a proposed wind turbine these fluctuations should therefore be taken into account. Bearing in mind that the "time-constant" of an ordinary cup generator anemometer is about one sec., it seems likely that the output from a wind turbine would be noticeably affected only by eddies which last for several sec. Fluctuations of this size are easy enough to measure but there are two complications. First, it is not fluctuations of wind speed "at a point" that matter, but the fluctuations of the mean wind speed (or mean wind pressure?) over the area swept out by the turbine blades—a circle of up to 200 ft. in diameter. Second, the application of these measurements to the computation of the probable output from a wind turbine is complicated by the fact that wind direction is also varying. These variations of wind direction would have to be taken into account and estimates would have to be made about the speed of response of the control gear. These difficulties may explain why the author, who bases his estimates of output on hourly means, makes no quantitative assessment of the effect of these fluctuations. The nearest approach to such an assessment is when it is shown that the ratio

$$\frac{\int_0^T v^3.dt}{T} \Big/ \left(\frac{\int_0^T v.dt}{T}\right)^3$$

is very near unity at speeds greater than 45 m.p.h. These speeds are, however, well above the rated speed of any likely wind turbine and at such speeds fluctuations, provided that the speed does not fall below the rated speed, do not affect the output at all. The ratio may differ appreciably from unity at lower speeds and the output over a period of 1 hr. may differ significantly from that computed from the hourly mean wind.

Apart from their effect on the integrated output, and therefore on the economy, of a wind turbine, the fluctuations in output which result from wind fluctuations may be more directly embarrassing. Where generators are used to feed into a National Grid, as could be the case in this country, operating mainly as fuel savers, fluctuations over fairly long periods would not matter and fluctuations over shorter periods could be smoothed out by having a large number of generators connected to the network. But where the generator is not connected to a grid then fluctuations would usually mean that some sort of storage facility (either of electricity or of energy in some other form) would be required. Golding lists possible energy storage devices and estimates that the cost of power production may well be doubled if storage is needed.

Rather more than half of this book is devoted to the meteorological aspects of the generation of electricity by wind power. In addition to discussion of the importance of wind fluctuations there is some account of wind flow over hills and a description of wind surveys that have been carried out in various countries. The author is not a meteorologist and, inevitably, faults can be found in these sections. The definition of an isobar as "a line joining points having the same atmospheric pressure (at sea level and corrected for temperature and latitude)" shows confusion of thought, or of understanding, between reducing pressure to sea level on the one hand, and measuring atmospheric pressure using one particular pressure-measuring device, a mercury barometer, on the other. Again the statement "A hill may accelerate the wind over the summit, through compression of the lower layers of air by those above" does

not really describe what happens. There are also a number of errors of fact. Beaded edges to the cups of anemometers, for example, were introduced for greater strength, not ". . . to improve the constancy of rate of revolution" (whatever that may mean). But these are small points. The author has collected together a vast and, for anyone interested in the subject of the generation of electricity by wind power, a valuable bibliography (whilst, oddly enough, omitting a paper by C. E. P. Brooks*, which was written specifically in connexion with the generation of electricity from the wind) and he has prepared a number of useful summaries and tables (again not entirely free from error).

The book is well produced, with few printing errors. A list of Tables would have been useful and the Index is noticeably incomplete.

R. FRITH

The structure of turbulent shear flow. By A. A. Townsend. 8½ in. × 5½ in., pp. xii + 154, *Illus.*, Cambridge University Press, 1956. Price 40*s*.

The present book is one of a series of monographs which began in 1953 with Dr. G. K. Batchelor's "The theory of homogeneous turbulence". As is evident from the title, the latter work excluded application to the atmosphere in general, though the possibility of the existence of an approximation to homogeneity in the turbulence in certain conditions away from the earth's surface is not to be ignored. However, for the most part atmospheric motion does involve shear of some form or other, and because of this Dr. Townsend's volume which is concerned with the physical properties of turbulent flow in the presence of shear, will draw considerable interest from meteorologists.

The growth of our understanding of turbulent motion is well known to be greatly dependent on experimental observation and, as Dr. Townsend explains in his preface, the ideas which he develops are essentially an outcome of experimental studies conducted over the past few years in the Cavendish Laboratory School. Indeed, one of the stated reasons for the book is the connected presentation of studies which have hitherto been described in various papers, and of an individual interpretation thereof, in an attempt to provide a "physically consistent description of turbulent shear flow".

After a general introduction and a chapter dealing with the equations of motion, Dr. Townsend first discusses certain simplified types of flow, especially isotropic homogeneous turbulence, with the expressed object of forming a general basis for the understanding of more complicated flows involving shear. In particular, he sets out the ideas of "self preservation" and "Reynolds number similarity", which are his terms for the existence of a universal character in the distribution of turbulent properties at various times in the flow and at various Reynolds numbers. These ideas are applied and developed in discussions of shear flow, at first on a very general basis, and then with reference to the special flows in wakes, jets, pipes and channels, and in boundary layers with and without pressure gradient.

It is of course not to be expected that a treatment of the present type will provide material for immediate discussion in relation to our atmospheric problems of turbulent mixing and transport, for the substance of the treatment is

* BROOKS, C. E. P.; Frequency of winds between given velocities. *Met. Mag., London*, **78**, 1949, p. 33.

that very feature which until recently has been so little explored in the atmosphere, namely the actual properties, as distinct from the effects, of turbulent motion. The real value to meteorology lies in the demonstration of the progress which has been made in building up a physical description of laboratory flow, by elaborate measurement of the intensities, stresses, scales and spectral distributions in the turbulent motion. Interest in studying these properties in atmospheric flow has grown rapidly in the last few years, and it is in this direction that we should ultimately profit from the impressive collection of data, and the penetrating discussion thereof, which are now presented in Dr. Townsend's book.

F. PASQUILL

Le temps et les travaux des champs. By A. Viaut and J. Sanson, 7½ in. × 5½ in., pp. 144., *Illus.*, Presses Universitaires de France, Paris, 1953. Price: 500 *fr.*

This book would appear to live up to its sub-title "Conseils aux agriculteurs" whilst also containing much of interest to the professional meteorologist.

Chapters 1 and 2 outline the methods of preparing short-range (12-48 hr.) and medium-range (5–6 day) forecasts with special emphasis on their relevance to agricultural operations on similar time scales. The "on-site" meteorological observation needed if the maximum value is to be gained from the general forecasts are described at some length in Chapter 3. Chapter 4 deals with sunshine and radiation indicating some connexions between the global radiation experienced by the vine and the quality of the subsequent wine. Temperature, frost, frost prevention and some relationships between plant growth and temperature, including damage by frost, form the subject of Chapter 5. Chapter 6, on precipitation and humidity, contains some useful information on the effectiveness of a given fall of rain taking into account infiltration into the soil and evaporation. We are also told that the main meteorological stations will supply by telephone information on the vertical structure of the atmosphere to anyone contemplating "cloud seeding" operations. The beneficial and deleterious effects of wind on plants are only briefly reviewed in Chapter 7, but Chapter 8, on the importance of the knowledge of climatology to agricultural scientists, is worth close study. Chapter 9 on the forecasting of crop yields from weather data sets out methods adopted by the French to solve a problem which has so far defeated the efforts of investigators in this country. The effects of weather and climate upon industries serving agriculture are briefly reviewed in Chapter 10 and the final chapter outlines the use of aircraft to aid food production.

Different sections may appeal to different readers, but no one can fail to note both the efforts which the French Meteorological Office takes to assemble their information in a form related as closely as possible to the many types of agricultural enterprise, and their attempts to frame a suitable organization for disseminating the information.

R. W. GLOYNE

HONOURS AND AWARDS

Mr. C. S. Durst, Senior Scientific Officer, formerly Assistant Director (Special Investigations), Meteorological Office, has been awarded the Bronze Medal of the Institute of Navigation for 1956 for his paper, "The accuracy of dead reckoning in the air", published in the April 1955 number of the Institute's Journal.

BOOK RECEIVED

A proposal for the Hawaii Institute of Geophysics. 8½ in. × 11 in., pp. 16, *Illus.* University of Hawaii, *s.a.*

ERRATA

SEPTEMBER 1956, PAGE 284, line 27; *for* "one part in 107 has a third." *read* "one part in 10^8 has a third."

NOVEMBER 1956, PAGE 345, Fig. 1; In the county of Middlesex *insert* "9·7".

METEOROLOGICAL OFFICE NEWS

A letter was received by Dr. J. Pepper, M.O.6, from the Flag Officer H.M. Yacht *Britannia*, stating he was instructed by H.R.H. the Duke of Edinburgh to say that His Royal Highness was glad to accept the copy of "Meteorology of the Falkland Islands and Dependencies, 1944–50", presented by the author.

Academic successes.—The following members of staff have been successful in examinations; we offer them our congratulations. General Certificate of Education (Advanced Level):

Senior Aircraftman K. C. Adamson and Senior Aircraftman M. F. Smith.

Swimming.—At the Air Ministry Swimming Gala held at Messrs. Bourne and Hollingsworth's Baths in Gower Street on October 11, Mr. A. R. Evling was second in the Backstroke Championship and third in the Free Style and Breaststroke Championships. Miss K. E. Payne was third in the Ladies' Championship and won the Ladies' Handicap.

Horticultural Show.—At the Air Ministry Horticultural Society's autumn show held in Whitehall Gardens on October 4, Miss H. G. Chivers and Messrs. B. G. Brame and H. A. Scotney gained prizes. Mr. Scotney was runner up for the Banksian Medal (the aggregate prize for the year) and also runner up for the aggregate for the autumn show.

WEATHER OF OCTOBER 1956

The main cyclonic activity in the Atlantic was of usual intensity but transferred well north and north-east of normal.

Lowest pressure for the month was about 1000 mb. between Iceland and Greenland and near Jan Mayen (maximum anomalies −7 mb.). Correspondingly, the main high-pressure belt was shifted north and appeared as two cells, one centre with mean pressure for the month 1024 mb. near 42°N. over New England and over the St. Lawrence valley, the other with similar pressure values over Biscay and extending its influence over Great Britain and continental Europe as far as 55°–60°N. and south-east to the Balkans. The greatest pressure anomaly was +11 mb. near south-west Ireland, attributable more to abnormality of position than intensity which was within the most usual figures.

There was an important col over the Atlantic near 40°W. between the American and European high-pressure cells, but pressure was above normal everywhere between 40° and 55°N.

Our search for anomalies up stream (in the sense of the upper westerlies) which might explain the shift of the main centres of action in the Atlantic region reveals that the north-western half of Canada and a strip south along the Rockies and American west coast to 40°N. was everywhere colder than normal (greatest anomalies −5°C. to −6°C, in and near the Yukon). The rest of North America (the greater part) was 0°C. to 3°C. warmer than normal. Deep depressions on the Pacific carried the lowest pressure well east close to the tip of British Columbia instead of the usual position over the Alaska peninsula. Thus cold air of the rear side of these depressions spread over all Alaska and was swept round over the Alaskan Gulf to the west coast of Canada and the United States. This appears to have established the North American cold trough in an unusually western position, steering cyclonic activity towards high latitudes on either side of Greenland.

Rainfall was deficient in the central regions dominated by the west European and east American anticyclones, but was above normal over most of Germany. There was excess rainfall over the western and central Rockies and Southern Alaska. Most of India also had much rain, great excesses occurring in the north-west.

The British Isles had showery and cold weather during the first week of the month as complex depressions north of Scotland moved eastward to Scandinavia, but weather during the second week was warmer and anticyclonic. During the latter half of the month a westerly air stream brought a return to less settled conditions; weather became much cooler on the 24th as winds veered to a northerly point.

On the 1st a developing warm-front wave moved slowly north-east from our south-west approaches across southern England giving substantial rainfall over a wide area. Flooding occurred at many places in and around London; London Airport recorded 2·16 in. of rain in 12 hr., nearly as much as the normal for the whole month. Wind veered to the north-west on the 3rd and weather became cold and showery for the next three or four days with scattered thunderstorms. The first snow of the season fell on some of the higher peaks of Scotland and northern England during this period. There was drizzle in many places on the 7th and some local thunderstorms on the 8th as warm air from the Atlantic spread over the country. Next day pressure began to rise over the British Isles and by the 10th a belt of high pressure extended from north of the Azores, across the Midlands, to Austria. Weather was generally dry until the 15th with night fog over England and Wales which persisted into the afternoon in many places; temperatures rose steadily, widely exceeding 60°F. and reached 70°F. at Kinloss (Morayshire) on the 15th. During the next two days a deep depression moving north-eastwards passed between Scotland and Iceland bringing to most places on the 16th their first substantial rainfall for over two weeks, and on the 17th a return to cooler weather with westerly gales in Scotland. Another depression, following a parallel but more southerly track, crossed Scotland during the night of the 19th–20th and brought a renewal of widespread rain over the British Isles which was heavy at times in the west and north. Weather was dry in England and Wales on the 21st and 22nd as an anticyclone from the Azores moved eastward into Germany, but on the 24th an influx of arctic air from the north brought showers to all areas, which were heavy at times with hail and thunder; temperatures were about 10°F. lower the next day. Showers and scattered thunderstorms continued for two or three days and there was slight frost at night. On the 27th winds backed temporarily to the south-west and showers became less frequent as a tongue of warmer Atlantic air crossed the country. A depression developed on the tip of this warm-sector tongue as it reached the North Sea giving severe gales along our eastern seaboard on the 29th with frequent showers over most of the country, which were of hail locally, and of snow over some high ground in the north. Gales moderated slowly the next day as pressure rose over Northern Scotland and the depression over the North Sea filled up. Pressure at Dyce, near Aberdeen, reached 1045·6 mb. on the 31st, 5 mb. higher than the previous October highest pressure in the British Isles which was recorded at Nottingham in 1877. The last two days of the month were mostly fine and cold.

Temperatures were about average for most of the month but dropped sharply during the last week. Sunshine was above average in most districts except in parts of east and south-east England and north and north-west Scotland. With 150 hr. during the month the North Riding of Yorkshire had nearly twice its normal amount of sunshine for the month. Rainfall was below average in nearly all areas except over north and north-west Scotland. It was less than half the average in counties bordering the south coast from Sussex to Devonshire, in South Wales, parts of the Midlands, Lincolnshire, the southern part of Yorkshire, parts of Northumberland and in the south-eastern coastal districts of Scotland. Most farm work has proceeded with little hindrance from the weather. Sunny days and frost-free nights without much heavy rain have enabled farmers to make good progress with their autumn cultivations including potato and sugar-beet lifting, cropping of broccoli and sprouts and planting out of spring *brassicae*.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	71	24	−1·0	57	−3	113
Scotland	70	21	0·0	90	−2	108
Northern Ireland ...	63	27	+0·1	91	−2	115

RAINFALL OF OCTOBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·24	85	*Glam.*	Cardiff, Penylan ...	2·72	57
Kent	Dover	2·46	63	*Pemb.*	Tenby	1·14	23
,,	Edenbridge, Falconhurst	1·56	43	*Radnor*	Tyrmynydd	4·11	62
Sussex	Compton, Compton Ho.	1·88	41	*Mont.*	Lake Vyrnwy	3·84	66
,,	Worthing, Beach Ho. Pk.	1·23	34	*Mer.*	Blaenau Festiniog ...	9·52	94
Hants.	St. Catherine's L'thouse	1·31	35	,,	Aberdovey	2·78	58
,,	Southampton (East Pk.)	1·74	44	*Carn.*	Llandudno	1·24	37
,,	South Farnborough ...	2·17	68	*Angl.*	Llanerchymedd ...	3·24	72
Herts.	Harpenden, Rothamsted	1·74	55	*I. Man*	Douglas, Borough Cem.	3·57	79
Bucks.	Slough, Upton	2·50	89	*Wigtown*	Newton Stewart ...	3·08	68
Oxford	Oxford, Radcliffe ...	1·80	62	*Dumf.*	Dumfries, Crichton R.I.	2·99	76
N'hants.	Wellingboro' Swanspool	1·47	58	,,	Eskdalemuir Obsy. ...	5·14	95
Essex	Southend, W. W. ...	1·21	48	*Roxb.*	Crailing	1·34	47
Suffolk	Felixstowe	1·29	56	*Peebles*	Stobo Castle	2·73	79
,,	Lowestoft Sec. School ...	3·76	135	*Berwick*	Marchmont House ...	1·98	52
,,	Bury St. Ed., Westley H.	1·70	63	*E. Loth.*	North Berwick Gas Wks.	1·32	45
Norfolk	Sandringham Ho. Gdns.	1·50	49	*Midl'n.*	Edinburgh, Blackf'd. H.	1·54	56
Wilts.	Aldbourne	2·04	57	*Lanark*	Hamilton W. W., T'nhill	3·59	110
Dorset	Creech Grange... ...	2·20	43	*Ayr*	Prestwick	3·30	115
,,	Beaminster, East St. ...	2·35	53	,,	Glen Afton, Ayr San. ...	4·42	87
Devon	Teignmouth, Den Gdns.	1·69	44	*Renfrew*	Greenock, Prospect Hill	3·70	73
,,	Ilfracombe	2·33	51	*Bute*	Rothesay, Ardencraig ...	2·61	59
,,	Princetown	4·32	51	*Argyll*	Morven, Drimnin ...	6·39	107
,,	Werrington Park ...	2·65	51	,,	Poltalloch	3·35	68
Cornwall	Penzance	2·54	55	,,	Inveraray Castle ...	6·47	92
,,	St. Austell	2·84	54	,,	Islay, Eallabus	3·54	74
,,	Scilly, Tresco Abbey ...	1·84	48	,,	Tiree	4·03	88
Somerset	Taunton	1·47	46	*Kinross*	Loch Leven Sluice ...	2·03	59
Glos.	Cirencester	1·32	39	*Fife*	Leuchars Airfield ...	1·15	44
Salop	Church Stretton ...	2·01	55	*Perth*	Loch Dhu	5·89	82
,,	Shrewsbury, Monkmore	2·01	72	,,	Crieff, Strathearn Hyd.	2·83	72
Worcs.	Malvern, Free Library...	1·26	42	,,	Pitlochry, Fincastle ...	2·48	76
Warwick	Birmingham, Edgbaston	1·64	54	*Angus*	Montrose Hospital ...	1·87	68
Leics.	Thornton Reservoir ...	1·32	47	*Aberd.*	Braemar	2·51	67
Lincs.	Boston, Skirbeck ...	0·75	27	,,	Dyce, Craibstone ...	2·90	86
,,	Skegness, Marine Gdns.	1·15	42	,,	New Deer School House	3·31	87
Notts.	Mansfield, Carr Bank ...	1·01	33	*Moray*	Gordon Castle	2·42	77
Derby	Buxton, Terrace Slopes	3·13	64	*Nairn*	Nairn, Achareidh ...	2·73	119
Chas.	Bidston Observatory ...	1·76	54	*Inverness*	Loch Ness, Garthbeg ...	4·71	132
,,	Manchester, Ringway...	2·26	73	,,	Loch Hourn, Kinl'hourn	11·58	117
Lancs.	Stonyhurst College ...	3·60	80	,,	Fort William, Teviot ...	9·19	129
,,	Squires Gate	2·23	63	,,	Skye, Broadford ...	8·59	113
Yorks.	Wakefield, Clarence Pk.	1·09	38	,,	Skye, Duntulm ...	5·59	109
,,	Hull, Pearson Park ...	1·05	35	*R. & C.*	Tain, Mayfield... ...	3·53	128
,,	Felixkirk, Mt. St. John...	1·61	56	,,	Inverbroom, Glackour...	6·32	112
,,	York Museum	1·24	46	,,	Achnashellach	10·14	135
,,	Scarborough	1·54	49	*Suth.*	Lochinver, Bank Ho. ...	5·73	125
,,	Middlesbrough... ...	1·00	33	*Caith.*	Wick Airfield	2·73	92
,,	Baldersdale, Hury Res.	2·83	76	*Shetland*	Lerwick Observatory ...	4·89	123
Nor'd.	Newcastle, Leazes Pk....	1·86	60	*Ferm.*	Crom Castle	3·30	102
,,	Bellingham, High Green	1·91	49	*Armagh*	Armagh Observatory ...	1·85	68
,,	Lilburn Tower Gdns. ...	1·58	43	*Down*	Seaforde	2·44	69
Cumb.	Geltsdale	3·75	101	*Antrim*	Aldergrove Airfield ...	2·07	69
,,	Keswick, High Hill ...	4·50	80	,,	Ballymena, Harryville...	3·63	98
,,	Ravenglass, The Grove	3·99	92	*L'derry*	Garvagh, Moneydig ...	3·99	115
Mon.	A'gavenny, Plâs Derwen	1·84	40	,,	Londonderry, Creggan	3·81	104
Glam.	Ystalyfera, Wern House	3·03	44	*Tyrone*	Omagh, Edenfel ...	4·00	109

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-36. K16.

	Per cent. of Av.
	57
	23
	62
	66
	94
	58
	37
	78
	79
	68
	76
	95
	47
	79
	52
	45
	56
	110
	115
	87
	73
	59
	107
	68
	98
	74
	88
	59
	44
	82
	72
	76
	68
	67
	86
	87
	77
	119
	132
	117
	129
	113
	103
	128
	112
	133
	125
	92
	123
	102
	68
	69
	66
	94
	115
	106
	100